Association of environmental tobacco smoke exposure with elevated home blood pressure in Japanese women: the Ohasama study

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Objective **Only a few of numerous epidemiological studies have demonstrated a positive association between environmental tobacco smoke (ETS) exposure and blood pressure (BP), despite experimental studies showing such a positive association. The association between home blood pressure (HBP) and ETS exposure was investigated in the general population.**

Methods **Five hundred and seventy-nine nonsmoking Japanese women were enrolled. The participants were classified into four categories according to their responses to a self-administered questionnaire: unexposed women (non-ETS), women exposed at home [ETS(home)], at the workplace/other places [ETS(work/other)] and at home and at the workplace/other places [ETS(both)]. Variables were compared using analysis of covariance adjusted for age, marital status, body mass index, diabetes mellitus, stroke, heart disease, hyperlipidemia, alcohol intake, salt intake and activity levels.**

Results **In participants without antihypertensive medication, systolic morning HBP in ETS(both) was 4 mmHg higher than that in non-ETS (116.8 ± 1.01 vs. 113.1 ± 1.08 mmHg, $P = 0.02$) and systolic morning HBP in ETS(home) and systolic evening HBP in ETS(both) were 3 mmHg higher than those in non-ETS (116.2 ± 1.07 vs. 113.1 ± 1.08 mmHg, $P = 0.04$; and 115.3 ± 1.02 vs. 111.9 ± 1.09 mmHg, $P = 0.03$, respectively). In participants with antihypertensive medication, ETS exposure status was not significantly associated with increased HBP levels.**

Conclusions **A positive association between HBP levels and ETS exposure was confirmed. HBP measurement is recommended in population-based studies investigating the effects of ETS exposure. ETS exposure may increase BP, thereby synergistically contributing to unfavorable cardiovascular outcomes along with other deleterious effects of ETS.** *J Hypertens* **28:000–000 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Abbreviations: ANCOVA, analysis of covariance; ANOVA, analysis of variance; BMI, body mass index; BP, blood pressure; CBP, casual clinic blood pressure; ETS, environmental tobacco smoke; ETS(both), participants exposed to ETS both at home and at the workplace and/or other places; ETS(everyday), participants exposed to ETS everyday; ETS(home), participants exposed to ETS at home; ETS(occasionally), participants exposed to ETS less frequently than everyday; ETS(work/other), participants exposed to ETS at the workplace and/or other places; HBP, home blood pressure; non-ETS, participants not exposed to ETS

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Introduction

Exposure to environmental tobacco smoke (ETS) is a well known risk factor for morbidity and mortality from cardiovascular diseases such as coronary heart disease [1] and stroke [2–9]. Numerous studies have investigated the pathophysiological changes caused by ETS exposure, and one of the findings of these studies is that ETS causes endothelial dysfunction, such as impaired endothelium-dependent vasodilatation [10–14] and decreased nitric oxide production [15]. Some experimental studies have also shown that blood pressure (BP) is elevated for a short time period [16] or for 24 h after brief ETS exposure [15].

These pathophysiological and hemodynamic findings imply that ETS exposure increases BP in the general population. To the best of our knowledge, however, only a few of the numerous epidemiological studies investigating this relationship have shown a positive association between chronic ETS exposure and BP [17,18]. One possible reason for these inconsistent findings is that

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most results are based on measurement of casual clinic blood pressure (CBP), which is less sensitive in detecting true changes in BP compared to home blood pressure (HBP) measurement [19,20]. HBP is measured by individuals themselves at home with a validated device over a long observation period, providing more reproducible and reliable values with less random error, without observer bias and without the white-coat effect [19,20]. Because of these advantages, HBP values have better predictive power for morbidity and mortality from cardiovascular diseases than CBP values [19–22], and HBP monitoring is now widely recommended in guidelines [19,21] and in a scientific statement [20].

To test the hypothesis that HBP measurements detect differences in BP between individuals exposed and those not exposed to ETS in the general population, the association between HBP values and ETS exposure was examined in a population-based, cross-sectional study.

Methods

Study population

The study was conducted as a part of the Ohasama study, a Japanese community-based, BP measurement project [23,24]. The total population of Ohasama was 7202 in 1998. Of this total population, 4964 were 35 years old or older. Of those, 1410 working outside of the town were considered ineligible and excluded from the study because they were not in the town during normal working hours. Of the remaining 3554 individuals, 213 were also excluded from the study because they were hospitalized, mentally ill, or bedridden. A total of 3341 participants were thus eligible for the study. A questionnaire was sent to each participant, and 1895 of the eligible participants gave their informed consent and responded to the questionnaire. Of those, 585 were excluded from the analysis because they were ex-smokers or current active smokers. Thus, the number of lifelong nonsmokers was 1310. Another 505 individuals with incomplete answers to the questions regarding demographic factors including ETS exposure were also excluded. Of the remaining 805 individuals, 754 who measured their HBP in the morning on at least three occasions (3 days) during the 4-week study period were included. This criterion was based on our previous observation that the average BP on the first three occasions was not significantly different from the mean for the entire study period [23]. Men ($n = 175$) were also excluded from the analysis because their number was small. Therefore, the study included 579 women [54.9% of the total number of lifelong nonsmoking women ($n = 1054$)].

Table 1 compares the characteristics of the included study participants with lifelong nonsmoking women who participated in the study but were ultimately excluded from the analysis due to incomplete data on ETS exposure (nonparticipants). The participants were characterized by a lower mean age, by lower percentages of participants taking antihypertensive medication and having a history of stroke and by higher percentages of participants being married and current drinkers.

Table 1 Characteristics of participants and nonparticipants in lifelong nonsmoking women ($n = 998$)

	Participants	Nonparticipants[a]	*P* value
N	579	419	
Mean age (years)	59.2 ± 13.1	64.1 ± 11.2	<0.0001
Marital status (married %)	71.0	61.3	0.0014
BMI (kg/m^2)	23.7 ± 3.3	23.7 ± 3.4	NS
Antihypertensive medication (%)	18.1	25.1	0.0081
History			
Diabetes mellitus (%)	8.6	9.3	NS
Stroke (%)	1.0	2.9	0.0323
Heart disease (%)	6.0	5.0	NS
Hyperlipidemia (%)	12.1	14.8	NS
Alcohol intake (current drinker %)	24.5	15.0	0.0003
Salt intake (≥12.28 g/day %)	50.1	43.9	NS
Time spent walking (≥1 h/day %)	79.8	81.1	NS

BMI, body mass index; ETS, environmental tobacco smoke. Student's *t*-test for continuous variables and χ^2-test for categorical variables. Continuous variables are expressed as mean ± SD. NS = $P > 0.05$. [a]Lifelong nonsmoking female participants who participated in the study but were ultimately excluded from the analysis due to incomplete data on ETS exposure.

Blood pressure and pulse rate measurement

The procedures used for HBP, pulse rate and CBP measurements, as well as the measuring devices, have been described elsewhere [23,25,26]. Briefly, physicians and public health nurses conducted health education classes to inform the participants about the HBP and pulse rate recording method, to teach them how to measure their own HBP and pulse rate, and to validate their ability to perform these tasks consistently. The women were then asked to measure their HBP and pulse rate every morning and evening and to record the results for 4 weeks. Measurements of morning HBP and pulse rate were made within 1 h of waking, before breakfast or taking any drugs, with the women seated and having rested for at least 2 min [27]. Measurements of evening HBP and pulse rate were obtained in a homologous way just before going to bed. The HBP and pulse rate of an individual were defined as the mean of all measurements obtained from that person. The mean ± SD numbers of morning HBP, morning pulse rate, evening HBP and evening pulse rate measurements were 22.6 ± 6.5 ($n = 579$), 22.4 ± 6.6 ($n = 567$), 22.8 ± 6.5 ($n = 577$) and 22.7 ± 6.6 ($n = 566$), respectively.

Two consecutive measurements of CBP were taken by a nurse or technician after the participant had been seated at rest for at least 2 min [23]. CBP was defined as the average of the two readings.

Blood pressure and pulse rate measuring device

HBP and pulse rate were measured with the HEM 701C (Omron Healthcare Co. Ltd, Kyoto, Japan), an automatic device based on the cuff-oscillometric method that

generates a digital display of systolic BP, diastolic BP and pulse rate. CBP was measured with a USM-700F (UEDA Electronic Works Co. Ltd, Tokyo, Japan), a fully automatic device based on the Korotkoff sound technique (a microphone method). The circumference of the arm was less than 34 cm in most cases, so a standard arm cuff was used for both BP measurements. All devices used in this study had been validated [25,26] and satisfied the criteria of the Association for the Advancement of Medical Instrumentation [28].

Definition of environmental tobacco smoke exposure

Environmental tobacco smoke exposure status was evaluated by the following two questions: 'How often are you exposed to smoke from cigarette smoking by other family members or guests at home?' and 'How often are you exposed to smoke from cigarette smoking by other persons at the workplace and/or other places?'. The women who responded 'hardly exposed' to both questions were categorized as those not exposed to ETS (non-ETS), whereas those who responded 'everyday', '3 or 4 days a week', '1 or 2 days a week' or 'occasionally' were categorized as those exposed to ETS. The exposed women were further classified into three categories according to their location of ETS exposure: those exposed to ETS at home [ETS(home)], those exposed to ETS at the workplace and/or other places [ETS(work/other)] and those exposed to ETS both at home and at the workplace and/or other places [ETS(both)]. For an additional analysis based on frequency of ETS exposure, the women who responded 'everyday' to either question were categorized as those exposed to ETS everyday [ETS(everyday)], whereas the remaining women who responded '3 or 4 days a week', '1 or 2 days a week' and 'occasionally' to either question were categorized as those exposed to ETS less frequently than everyday [ETS(occasionally)].

Data analysis

Information on smoking status, ETS exposure status, marital status, history of diabetes mellitus, history of stroke, history of heart disease, history of hyperlipidemia, alcohol intake, salt intake and activity levels (time spent walking per day) was obtained from the questionnaire. A standardized methodology was used to calculate dietary salt (NaCl) intake from a Japanese version of the food-frequency questionnaire. The reproducibility and validity of this version were previously reported in detail [29,30]. Information on age and use of antihypertensive medication was obtained from another questionnaire sent to each household at the time of the HBP measurements. Body mass index (BMI) information was obtained from medical records kept at Ohasama Hospital and from annual health check-up records.

The participants were stratified according to use of antihypertensive medication to avoid possible mitigation of pressor effect of ETS, because relatively small differences in BP between the participants exposed and those not exposed to ETS were expected to be detected from previous findings [17,18]. Variables were compared using the *t*-test, analysis of variance (ANOVA), χ^2-test, a logistic regression analysis adjusted for age (years) or analysis of covariance (ANCOVA) adjusted for age (years), marital status (married or single/divorced/widowed), BMI (kg/m^2), history of diabetes mellitus, history of stroke, history of heart disease, history of hyperlipidemia, alcohol intake (current drinker or not current drinker), salt intake (less than the median of 12.28 g/day or greater than or equal to the median) and time spent walking (less than 1 h/day or greater than or equal to 1 h/day), as appropriate. The level of statistical significance was set at $P < 0.05$. Data are presented as percentages or means ± SD (for the *t*-test and ANOVA) or means ± SE (for ANCOVA). All analyses were performed with SAS software version 9.1 (SAS Institute Inc., Cary, North Carolina, USA).

Results

Home blood pressure and pulse rate of the participants without antihypertensive medication

The characteristics of the study participants are presented in Table 2. Mean age, marital status and percentages of current drinkers were significantly different among the categories of ETS exposure status. This might have been due to the marked differences in age, because working women are usually younger than retirement age and their spouses may be comparatively younger and healthier. Younger women may also have more social opportunities to consume alcohol. A logistic regression analysis was performed to determine whether these factors are significantly different among the categories of ETS exposure status after adjusting for age. The results showed that marital status was not significantly different ($P = 0.40$), whereas percentages of current drinkers remained significantly different among the categories of ETS exposure status ($P = 0.01$).

Table 3 shows HBP and pulse rate levels by location of ETS exposure. The systolic morning HBP value in ETS(both) was approximately 4 mmHg higher than that in non-ETS ($P = 0.02$), and the systolic morning HBP value in ETS(home) and the systolic evening HBP value in ETS(both) were approximately 3 mmHg higher than those in non-ETS ($P = 0.04$ and $P = 0.03$, respectively). There was also a tendency for systolic morning HBP and systolic evening HBP values of all categories exposed to ETS to be higher than those in non-ETS. Systolic morning HBP and systolic evening HBP levels were not significantly different among the categories exposed to ETS, and diastolic HBP and pulse rate levels were not significantly associated with any ETS exposure status. There were no significant interactions between age and ETS exposure status on any HBP and pulse rate levels (all P for interaction >0.2).

Table 2 Characteristics of the participants without antihypertensive medication by ETS location ($n = 474$)

	non-ETS	ETS(work/other)	ETS(home)	ETS(both)	*P* value
N	143	47	129	155	
Mean age (years)	64.0 ± 10.7	47.7 ± 9.4	58.3 ± 12.8	52.3 ± 10.7	<0.0001
Marital status (married %)	64.3	85.1	72.9	83.2	0.0007
BMI (kg/m^2)	23.2 ± 3.2	23.4 ± 2.4	23.6 ± 3.5	23.5 ± 3.2	NS
History					
Diabetes mellitus (%)	6.3	8.5	8.5	7.1	NS
Stroke (%)	0.7	0.0	0.8	0.0	NS
Heart disease (%)	6.3	4.3	4.7	2.6	NS
Hyperlipidemia (%)	14.0	4.3	12.4	6.5	NS
Alcohol intake (current drinker %)	12.6	36.2	24.0	40.0	<0.0001
Salt intake (≥12.28 g/day%)	50.3	44.7	47.3	55.5	NS
Time spent walking (≥1 h/day %)	81.1	70.2	82.9	83.2	NS

BMI, body mass index; ETS, exposure to environmental tobacco smoke. Analysis of variance for continuous variables and χ^2-test for categorical variables. Continuous variables are expressed as mean ± SD. NS = $P > 0.05$.

Because percentages of current drinkers were significantly different among the categories of ETS exposure status after adjusting for age, subgroup analysis was performed in noncurrent drinkers. The results showed a similar tendency presented in Table 3 (data not presented).

Table 4 presents the results of the additional analysis based on frequency of ETS exposure. There was a similar tendency for systolic morning HBP and systolic evening HBP values of all categories exposed to ETS, including the values in ETS(occasionally), to be higher than those in non-ETS, as presented in Table 3. The results showed significant differences between the systolic morning HBP value in ETS(everyday) and that in non-ETS and between the systolic evening HBP value in ETS(everyday) and that in non-ETS ($P = 0.02$ and $P = 0.03$, respectively).

Home blood pressure and pulse rate of the participants with antihypertensive medication

Home blood pressure and pulse rate levels by location and frequency of ETS exposure ($n = 105$) showed no significant differences in systolic HBP values between any ETS exposure group and the non-ETS group ($P > 0.2$ and $P > 0.5$, respectively). No other HBP and pulse rate levels were significantly associated with any ETS exposure status (data not presented).

Casual clinic blood pressure and pulse rate of the participants without antihypertensive medication

Table 5 shows mean CBP levels by location of ETS exposure. CBP values were available from 296 (62.4%) study participants without antihypertensive medication. The systolic and diastolic CBP values in ETS(home) were significantly higher than those in non-ETS ($P = 0.02$ and $P = 0.04$, respectively). No other significant differences in CBP values were seen between any ETS exposure group and the non-ETS group ($P > 0.6$).

Discussion

The present results confirm that there is a relationship between increased HBP levels and ETS exposure in Japanese women without antihypertensive medication. HBP measurements detect approximately a 3–4 mmHg difference in BP between the ETS(home) and the ETS-(both) groups and the non-ETS group, whereas CBP measurements detect significant differences only between the ETS(home) group and the non-ETS group. Thus, HBP measurement is a more sensitive measurement for detecting small BP changes.

In the present study, systolic morning HBP values in ETS(home) and in ETS(both) and systolic evening HBP value in ETS(both) were significantly higher than those in non-ETS, whereas diastolic HBP and pulse rate levels were not significantly associated with any ETS exposure status. These findings are consistent with those of Heiss *et al.* [15] and Mahmud and Feely [16], who investigated the relationship between ETS exposure and BP levels in experimental studies. Makris *et al.* [17] investigated the association between ambulatory BP values and ETS exposure in 254 clinically normotensive nonsmokers who were self-referred to their outpatient

Table 3 HBP and PR of the participants without antihypertensive medication by ETS location

	non-ETS	ETS(work/other)	ETS(home)	ETS(both)
Systolic morning HBP (mmHg)	113.1 ± 1.08	114.7 ± 1.85	116.2 ± 1.07[a]	116.8 ± 1.01[a]
Diastolic morning HBP (mmHg)	71.0 ± 0.73	71.4 ± 1.24	71.6 ± 0.72	72.0 ± 0.68
Morning PR (beats/min)	66.2 ± 0.62	66.9 ± 1.06	66.9 ± 0.63	66.9 ± 0.59
Systolic evening HBP (mmHg)	111.9 ± 1.09	114.2 ± 1.86	114.3 ± 1.08	115.3 ± 1.02[a]
Diastolic evening HBP (mmHg)	69.0 ± 0.74	70.3 ± 1.26	69.4 ± 0.73	70.6 ± 0.69
Evening PR (beats/min)	68.7 ± 0.60	68.4 ± 1.02	68.7 ± 0.60	69.4 ± 0.57

BMI, body mass index; ETS, exposure to environmental tobacco smoke; HBP, home blood pressure; PR, pulse rate. Analysis of covariance. Data were adjusted for age, marital status (married or single/divorced/widowed), BMI, history of diabetes mellitus, history of stroke, history of heart disease, history of hyperlipidemia, alcohol intake (current drinker or not current drinker), salt intake (≥12.28 g/day or <12.28 g/day) and time spent walking (≥1 h/day or <1 h/day). Data are expressed as mean ± SE.
[a] $P < 0.05$ compared to non-ETS.

Table 4 HBP and PR of the participants without antihypertensive medication by ETS frequency

	Non-ETS	ETS(occasionally)	ETS(everyday)
N	143	155	176
Systolic morning HBP (mmHg)	113.0 ± 1.08	115.9 ± 0.98	116.7 ± 0.95[a]
Diastolic morning HBP (mmHg)	71.1 ± 0.72	72.0 ± 0.66	71.5 ± 0.64
Morning PR (beats/min)	66.2 ± 0.62	66.5 ± 0.57	67.2 ± 0.55
Systolic evening HBP (mmHg)	111.9 ± 1.08	114.2 ± 0.99	115.2 ± 0.96[a]
Diastolic evening HBP (mmHg)	69.1 ± 0.74	70.2 ± 0.67	69.9 ± 0.65
Evening PR (beats/min)	68.7 ± 0.60	68.6 ± 0.55	69.3 ± 0.53

BMI, body mass index; ETS, exposure to environmental tobacco smoke; HBP, home blood pressure; PR, pulse rate. Analysis of covariance. Data were adjusted for age, marital status (married or single/divorced/widowed), BMI, history of diabetes mellitus, history of stroke, history of heart disease, history of hyperlipidemia, alcohol intake (current drinker or not current drinker), salt intake (≥12.28 g/day or <12.28 g/day) and time spent walking (≥1 h/day or <1 h/day). Data are expressed as mean ± SE. [a] $P < 0.05$ compared to non-ETS.

hypertension clinic. Their results show that 24-h and daytime systolic BP, heart rate and daytime diastolic BP values are significantly higher in those with at least 1 h daily ETS exposure, compared with those with less exposure and those without ETS exposure. Although the study population and categories of ETS exposure status are different, the present results are consistent with their findings in that out-of-clinic BP measurements detect a difference in BP between women exposed and those not exposed to ETS.

Not only were the systolic HBP values of the ETS(home), the ETS(both) and the ETS(everyday) groups significantly higher than those in non-ETS, but systolic morning HBP and systolic evening HBP values of all categories exposed to ETS, including the ETS(work/other) and the ETS(occasionally) groups, tended to be higher than those in non-ETS in the present study. These findings indicate that ETS exposure may elevate systolic HBP regardless of location and frequency of exposure, which is consistent with the previous findings that even a small amount of ETS exposure causes detrimental effects at the clinical level [31,32]. Since systolic HBP is a strong predictive factor for morbidity and mortality from cardiovascular diseases [33,34], the present results may also reflect that a pressor effect, as well as other deleterious effects, of ETS exposure contribute to increased morbidity and mortality from cardiovascular diseases [1–9] in the general population.

Considering the fact that the pathophysiological and hemodynamic effects of ETS exposure last for 24 h after 30 min of ETS exposure at the experimental level [15], that the systolic HBP values of all categories exposed to ETS were consistently higher than those of the non-ETS group, and that the present results were obtained from multiple HBP measurements for a mean of 3 weeks, the present results may reflect a nonlinear persistent pressor effect caused by ETS exposure in the general population. Although there is a possibility that the present results may reflect a much shorter duration of pressor effects of ETS just after exposure, especially in the morning when many smokers tend to smoke just after waking, the present results are important from a prognostic hemodynamic standpoint. Since HBP measurement detects small BP changes, it may reflect persistent effects of ETS exposure and is more feasible to monitor a large population regularly, a further study using HBP measurement is necessary to clarify the chronic deleterious hemodynamic effects of ETS exposure at the population level, with more detailed data on ETS exposure status. HBP measurement may also be useful for future studies investigating the hemodynamic effects of other air pollutants, such as ambient particulate matter [35].

Differences in HBP between women exposed and those not exposed to ETS were not observed in women with antihypertensive medication. This might be because the relatively small pressor effect of ETS exposure was mitigated by the large BP-lowering effects of antihypertensive drugs. It is necessary to consider a pressor effect of ETS exposure at least when interpreting HBP data from normotensive or prehypertensive patients in clinical practice. The present results obviously raise concerns over public health. Achievement of smoke-free environments is thus also important from a hemodynamic standpoint.

Several limitations of the present study need to be discussed. First, as more detailed data on time, duration

Table 5 CBP of the participants without antihypertensive medication by ETS location ($n = 296$)

	non-ETS	ETS(work/other)	ETS(home)	ETS(both)
N	102	21	96	77
Systolic CBP (mmHg)	126.6 ± 1.46	125.4 ± 3.24	131.5 ± 1.46[a]	126.5 ± 1.68
Diastolic CBP (mmHg)	71.6 ± 0.89	70.8 ± 1.98	74.2 ± 0.89[a]	72.4 ± 1.03

BMI, body mass index; CBP, casual clinic blood pressure; ETS, exposure to environmental tobacco smoke. Analysis of covariance. Data were adjusted for age, marital status (married or single/divorced/widowed), BMI, history of diabetes mellitus, history of stroke, history of heart disease, history of hyperlipidemia, alcohol intake (current drinker or not current drinker), salt intake (≥12.28 g/day or <12.28 g/day) and time spent walking (≥1 h/day or <1 h/day). Data are expressed as mean ± SE. [a] $P < 0.05$ compared to non-ETS.

and quantity of ETS exposure were unavailable in our study population, the dose–response relationship between HBP levels and ETS exposure is unknown. A further study using HBP measurement is necessary with more detailed data on ETS exposure status. Second, although age distribution of the categories of ETS exposure status was uneven, age did not significantly interact with ETS exposure status on the present results. Third, as the study was cross-sectional, the results do not show a causal relationship between ETS exposure and BP elevation or development of hypertension. A longitudinal study is necessary to investigate this causal relationship in the Ohasama study, as well as in other populations. Fourth, the study excluded men due to the small number of lifelong nonsmoking men. It remains to be investigated whether a positive association between ETS exposure and BP is present in men. Lastly, since a biological marker of ETS exposure, such as cotinine concentration, was not measured, there may be misclassification of ETS exposure status. However, ETS exposure status in a self-administered questionnaire is shown to be generally accurate in a large-scale cohort study in a Japanese population, with a slightly higher rate of passive smokers falsely reporting themselves to be nonpassive smokers compared to Western studies [36]. Therefore, we believe that the present results are acceptable, but they may underestimate the true magnitude of the hemodynamic effects of ETS exposure due to these misclassifications.

In conclusion, this is the first population-based study demonstrating a significant association between increased HBP and ETS exposure. HBP measurement is recommended to investigate the effects of ETS exposure in the general population. ETS exposure may increase BP levels, which may synergistically contribute to unfavorable cardiovascular outcomes, along with the other deleterious effects of ETS.

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